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Hawaii Regional Sediment Management: Regional Sediment Budget for the Poipu Region of Kauai, HI

Edited by Jessica H. Podoski

PURPOSE. This Coastal and Hydraulics Engineering Technical Note (CHETN) reviews the development of a regional sediment budget for the Poipu Region on the Island of Kauai, HI, as part of the Hawaii Regional Sediment Management (RSM) initiative funded by the US Army Corps of Engineers (USACE) RSM Program. This document discusses the methodology used for determining sediment transport rates and presents final rates for each littoral cell. The rates presented were used to create the present-day sediment budget for the Poipu Region using the Sediment Budget Analysis System (SBAS) software.

BACKGROUND. RSM refers to the beneficial use of littoral, estuarine, and riverine sediment resources in an environmentally effective, operationally efficient, and economically feasible manner. The principles of RSM change the focus of engineering activities from the local or project-specific scale to a broader scale defined by the natural sediment processes. A prime motivator for implementing RSM principles and practices in Federally authorized navigation, storm damage reduction, and environmental restoration projects is their potential to reduce construction, maintenance, and operation costs, and to positively impact projects' ability to meet their authorized purposes.

The overall RSM strategy of the US Army Engineer District, Honolulu (POH), is to investigate RSM opportunities along all shoreline regions in Hawaii. Initial RSM regions on Kauai include the Kekaha Region and the Poipu Region on the west and south shores of the Island, respectively (Figure 1). There are no Federally sponsored projects in the Poipu Region. This CHETN pertains to the Poipu Region only. The Kekaha Region is addressed in Podoski (2013).

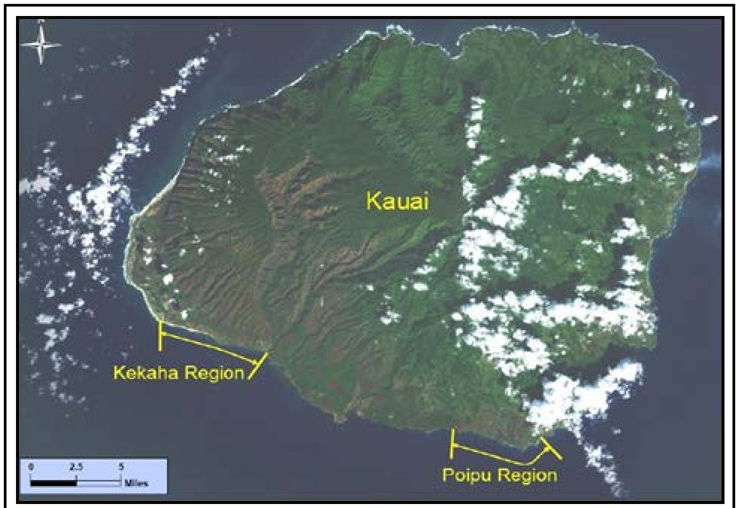

Figure 1. Initial RSM efforts on Kauai concentrated on the Kekaha Region and Poipu Region.

POIPU REGION. The Poipu Region extends from Lawai Bay on the west to Shipwreck Beach on the east. The eight littoral cells that define the 5.5 mile long Poipu Region shoreline [(1) Lawai, (2) Kukuiula Bay, (3) Hoai, (4) Punahoa, (5) West Poipu, (6) Central Poipu, (7) East Poipu, and (8) Shipwreck Beach] are shown in Figure 2. The region is defined by numerous small pocket beaches separated by rocky shoreline. Due to the nature of the shoreline, each cell is treated individually with the assumption that shoreline change is attributed only to onshore-offshore transport.

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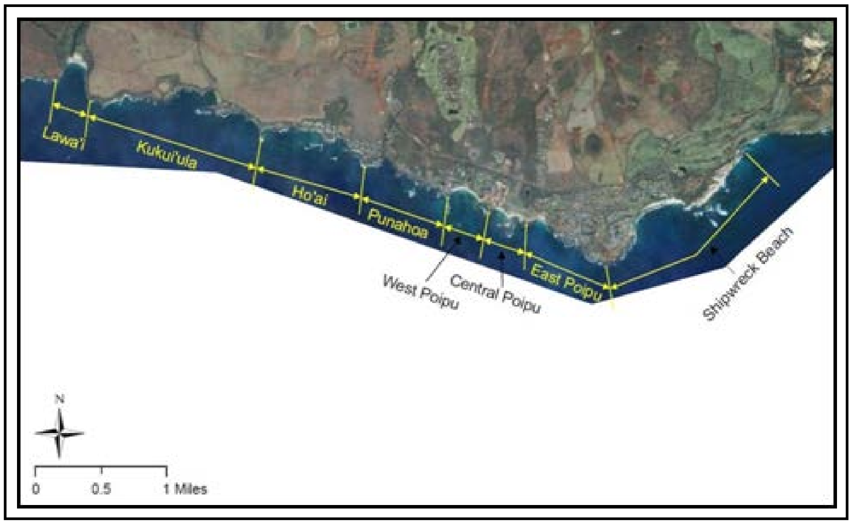

Figure 2. Littoral cells in the Poipu Region of Kauai.

The Lawai cell contains a 750-ft-long pocket beach bounded by basaltic headlands on either end. The Lawai Stream discharges into the bay, but its sediment yield rate is not known. The Kukuiula cell is located east of the Lawai cell. The cell consists primarily of a rocky shoreline with two pocket beaches (Spouting Horn Park and Kukuiula Landing Park). A jetty protects the southern end of the Kukuiula Harbor and a revetment protects ocean-front residential homes west of the harbor. The Hoai cell shoreline is composed of basalt rock headlands, sand perched on the rocky shoreline, and a sand beach. Shoreline protection in the form of seawalls and rock revetments are found within this cell. The Punahoa cell contains basaltic rock headlands and perched sand beaches. The Waikomo River discharges into the western portion of the cell. The river's sediment yield rate is unknown; however, there are no sand beaches in the vicinity, suggesting that the river has no meaningful contribution to the littoral cell. The West Poipu cell consists of a moderate-width pocket beach called Kaihuna Beach. The Central Poipu cell contains two arcuate beaches, Waiohai Beach to the west and Poipu Beach Park to the east. The beaches are separated by Nukumoi Point, which is a semi-detached headland with a large salient developed in its lee at Poipu Beach. At times in the past, the beach has extended to Nukumoi Point, forming a tombolo. The cell has the widest beaches within the Poipu study area. The East Poipu cell consists almost entirely of a rocky shoreline with the exception of Brennecke Beach fronting the Poipu Beach County Park. The Shipwreck Beach cell faces southeast and includes the rocky headland of Poipu, a small cobble beach within Keoniloa Bay, and high relief bluffs in the vicinity of Makawehi Bluff on its northern end. No shoreline protection exists along the cell.

APPROACH. The approach described by Podoski (2013) for the Kekaha Region applies equally to the Poipu Region.

POIPU REGION SEDIMENT BUDGET. The Poipu Region consists of eight littoral cells each of which can be described as a pocket beach bounded by pronounced rocky headlands and separated by long reaches of rocky shoreline. The geomorphology of this type of shoreline lends itself to having cross-shore sediment transport only, in which case there is no sediment exchange between neighboring cells.

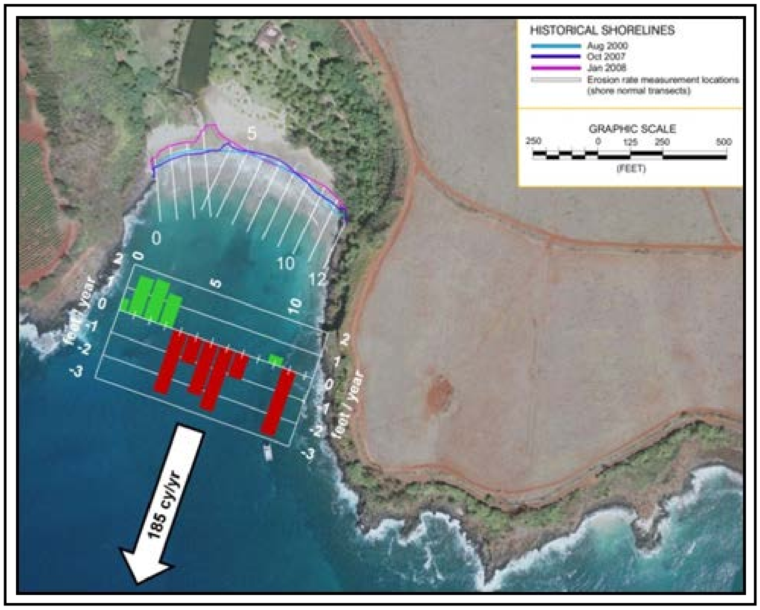

Figure 3. Lawai cell shoreline change rates and sediment budget, 2000-2007.

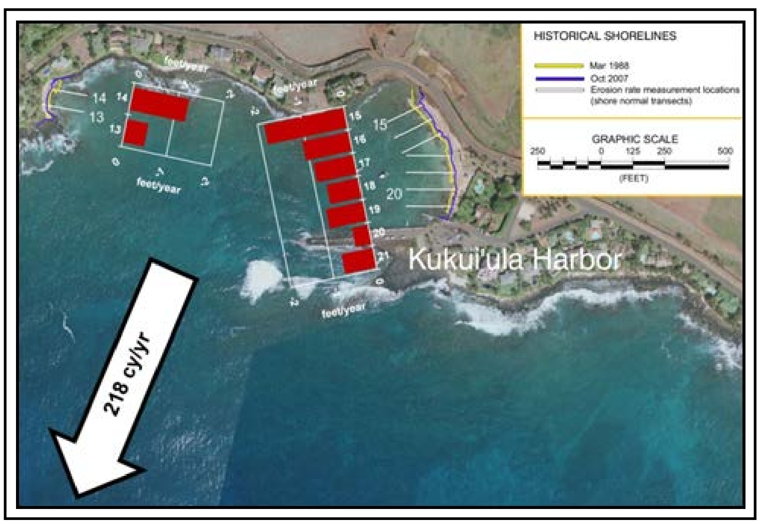

Figure 4. Kukulula Bay cell shoreline change rates and sediment budget, 1988-2007.

Lawai cell. The Lawai cell encompasses Lawai Bay and a 750-ft-long beach that eroded at an average rate of 185 cubic yards per year (cu yd/yr) from 2000-2007 (Figure 3). Due to the rocky shoreline adjacent to the beach, the transport is considered to be onshore-offshore only. Figure 3 also shows the 2008 historical shoreline that highlights the short-term dynamics of the beach. There may also be seasonal alongshore transport within the cell. Sediment influx to the cell from Lawai Stream is unknown.

Kukuiula Bay cell. The Kukuiula Bay cell consists of a rocky shoreline, Kukuiula Small Boat Harbor, and small beaches at Spouting Horn Park and Kukuiula Landing Park. The beaches eroded at 1 to 2 feet per year (ft/yr) for a combined erosion rate of 218 cu yd/yr from 1988–2007 (Figure 4). Kukuiula Landing Park was nourished with 500 cu yd of sand in 2001, and Kukuiula Small Boat Harbor was reportedly dredged within the last 10 years (volume unknown).

Hoai cell. The Hoai cell consists of a rocky shoreline, a developed headland, and two stretches of narrow sandy shoreline. The shorelines eroded at up to 2 ft/yr for a combined erosion rate of 386 cu yd/yr from 1988-2007 (Figure 5).

Punahoa cell. The Punahoa cell consists of a rocky shoreline with narrow perched beaches that eroded at a combined 100 cu yd/yr from 1988-2007 (Figure 6).

West Poipu cell. The West Poipu cell contains a 1,400-ft-long arcuate beach that is situated between two headlands. The beach eroded by 839 cu yd/yr from 1999-2007 (Figure 7). The eastern half of the shoreline experienced greater erosion, with typical rates of 2 to 4 ft/yr as opposed to the western portion which experienced erosion with rates typically less than 1 ft/yr.

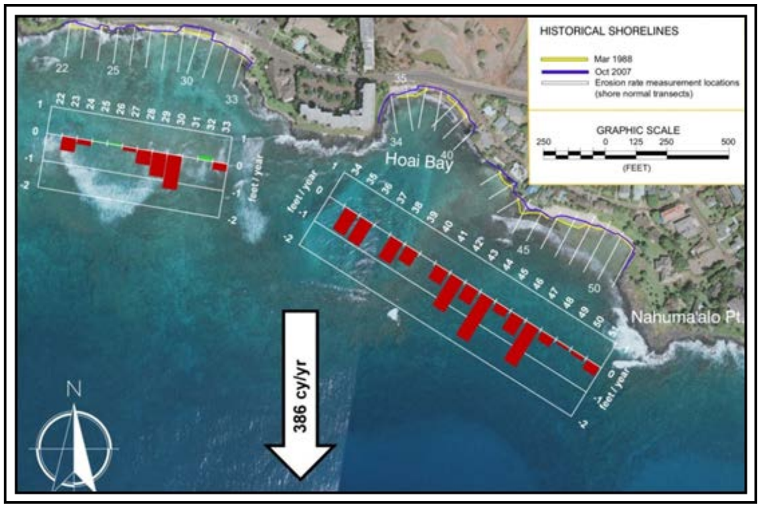

Figure 5. Hoai cell shoreline change rates and sediment budget, 1988-2007.

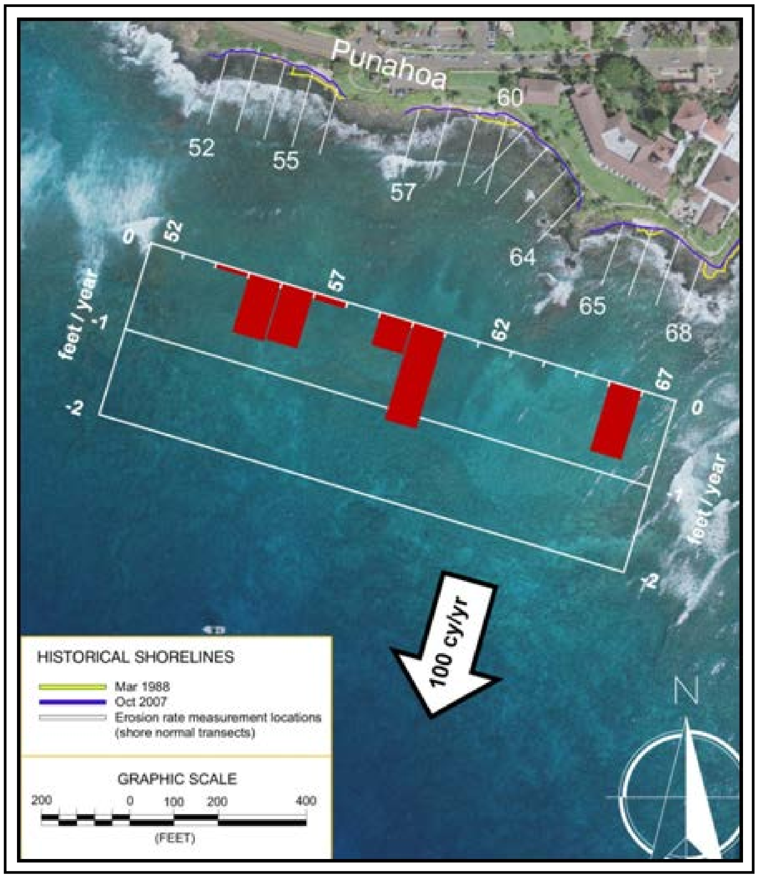

Figure 6. Punahoa cell shoreline changes rates and sediment budget, 1988-2007.

Central Poipu cell. The Central Poipu cell contains two arcuate beaches, Waiohai Beach to the west and Poipu Beach Park to the east. Sea Engineering (2012) recently completed a comprehensive study of Poipu Beach Park for the County of Kauai, including a year of quarterly beach profiles, wave and current measurements, wave hindcasts, and numerical modeling of wave and wave-generated currents. Poipu Beach Park and the adjacent Waiohai Beach are deeply embayed shorelines separated by the islet of Nukumoi Point. The wave refraction and diffraction processes around the islet are responsible for the formation of a salient that divides two embayments. For most of the known history of the area, the salient has extended to Nukumoi Point and formed a tombolo that separates the two embayments into individual littoral cells. During the post-Hurricane Iniki period in the 1990s, as well as the 2000s, the tombolo became an intermittent feature. It has been stable since approximately January 2010.

The study included five profiling surveys conducted from January to December 2011. The profile measurements show that most shoreline change occurs in the vicinity of the tombolo. From 15 May to 15 December 2011, the tombolo crest migrated a distance of 38 ft. Shoreline change diminished in both embayments with distance away from the tombolo. The volume change over the course of the profile surveys indicated a net gain in sand volume of 380 cu yd for the Central Poipu cell. Changes in net volume between individual surveys, however, ranged between +568 cu yd and –477 cu yd. As the

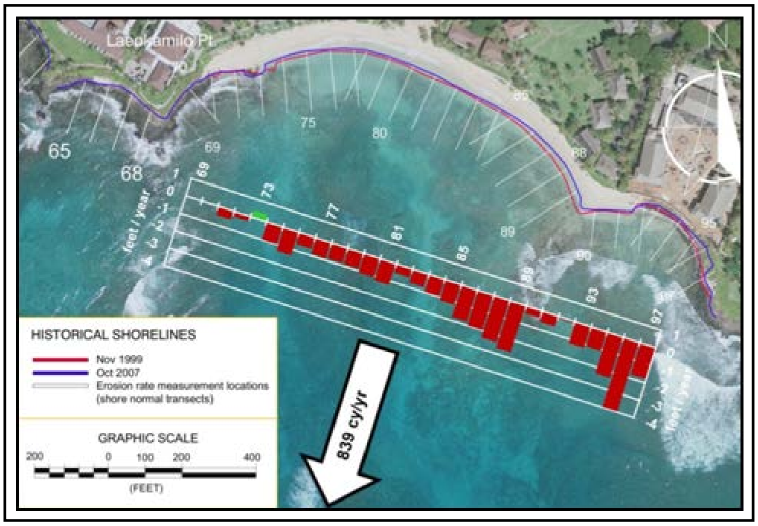

Figure 7. West Poipu cell shoreline change rates and sediment budget, 1999-2007.

beach was relatively stable over the course of the study, these numbers can be interpreted as normal variations in the beach profiles and beach sand volumes.

Numerical modeling indicates that Poipu Beach is more affected by trade wind waves, while Waiohai Beach is more affected by southern swell. The strongly bimodal wave climate characterized by the simultaneous occurrence of southern swell and trade wind waves is essentially balanced on either side of Nukumoi Point. Movement of the tombolo occurs as the balance shifts with the variation in incident wave conditions. When separated by the tombolo, the Poipu and Waiohai embayments are essentially separate littoral cells with some leakage occurring due to overwash across the tombolo. During periods when the tombolo has been breached, a strong current is present from Poipu to Waiohai. The strong current has been observed to transport beach sand from Poipu Beach to Waiohai Beach.

The occurrences of Hurricanes Iwa in 1982 and Hurricane Iniki in 1992 caused severe erosion of the beach park. Extreme events such as these are likely responsible for the disappearance of sand observed in the aerial photographic record. Strong currents generated by extreme wave heights can move sand offshore where it is no longer part of the littoral cell. Slow accretion of sand may take place in the interim periods. Figure 8 shows erosion in the Central Poipu cell of 691 cu yd/yr for the years 1999-2007.

East Poipu cell. The East Poipu cell contains Brennecke Beach, a 175-ft-long beach situated in a small embayment. The beach was reportedly nourished with 8,000 cu yd of sand in the 1990s, although neither the volume nor the date could be confirmed (Moffatt and Nichol 2011). Historical shoreline analysis showed the beach to be accreting at 145 cu yd/yr with the shoreline advancing at rates of up to 4 ft/yr from 1999-2007 (Figure 9).

Shipwreck Beach cell. The Shipwreck Beach cell contains 1,400 ft of beach that is partially perched. The beach eroded at an average rate of 901 cu yd/yr from 2000-2007 (Figure 10).

Table 1 summarizes the shoreline change rates for the Poipu Region. The right-hand column contains the accretion/erosion rates calculated in the present study. The middle two columns contain the rates presented in the Kauai RSM strategy (Moffatt and Nichol 2011).

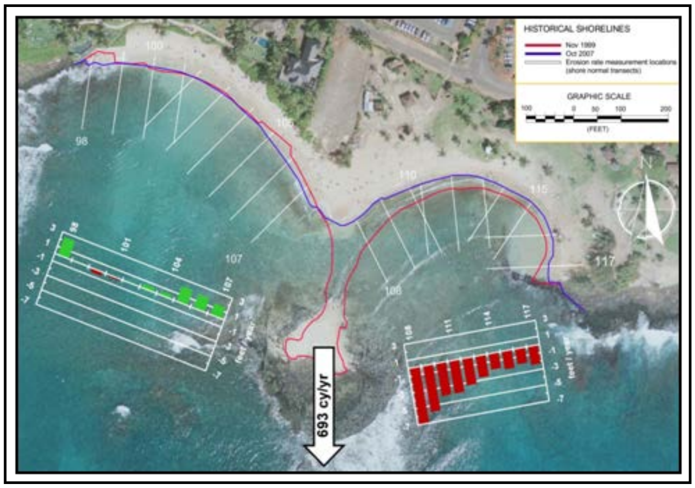

Figure 8. Central Poipu cell shoreline change rates and sediment budget, 1999–2007.

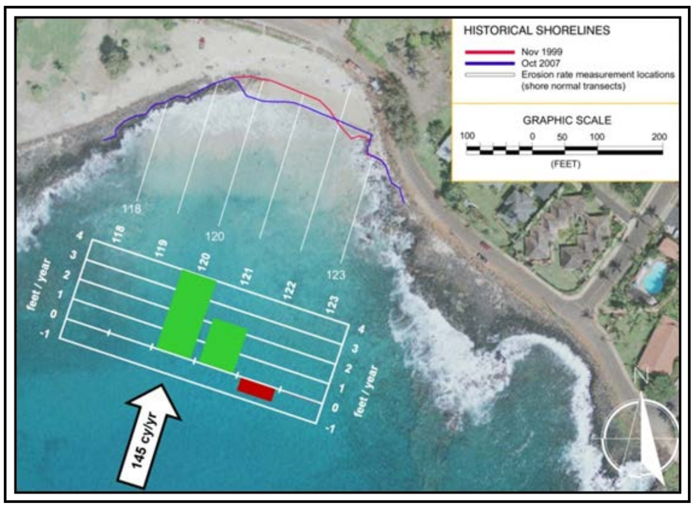

Figure 9. East Poipu cell shoreline change rates and sediment budget, 1999–2007.

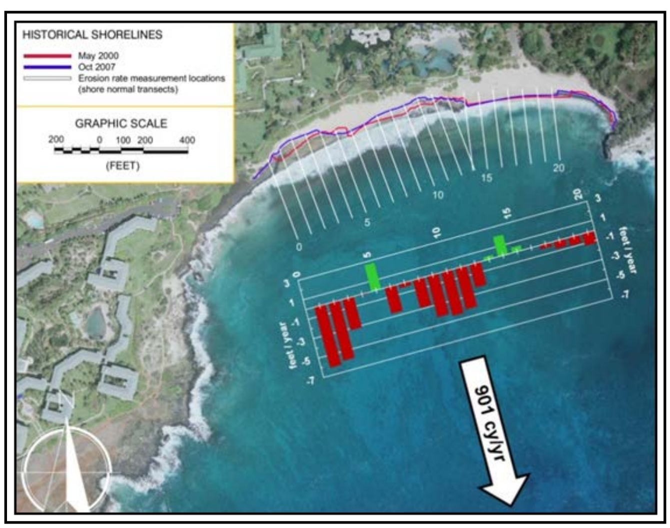

Figure 10. Shipwreck Beach cell shoreline change rates and sediment budget, 2000–2007.

Table 1. Poipu Region Long-term and Short-term Volume Change Rates.

Littoral Cell	Accretion(+) / Erosion(-) Rate Over Entire Period of Record (cu yd/year)*	Accretion(+) / Erosion(-) Rate Over Recent Period (cu yd/year)*	Accretion(+) / Erosion(-) Rate Over 2000-2007 Period (cu yd/year)
Lawai	–600	–200	–185
Kukuiula Bay	0	–250	–218
Hoai	+100	–250	–386
Punahoa	0	0	–100
West Poipu	–400	–400	–839
Central Poipu	–350	–800	–693
East Poipu	–150	+50	+145
Shipwreck Beach	–50	+200	–901
*Source: Moffatt and Nichol (2011).			

SEDIMENT BUDGETS USING SBAS. The final step in the sediment budget process was the use of the Sediment Budget Analysis System (SBAS) software for ArcGIS©10 toolbar (Rosati and Kraus 2001, Dopsovic et al. 2002) in combination with the sediment budget equation (Equation 1) to finalize cell balancing calculations, and to visually illustrate the calculated transport rates and directions as shown in Figure 11. The sediment budget equation is expressed as:

$$\Sigma Q_{source} - \Sigma Q_{sink} - \Delta V + P - R = \textbf{Residual} \quad (1)$$

where:

Q_{source} = sediment transport rate into the cell
Q_{sink} = sediment transport rate out of the cell
ΔV = volumetric change rate within the cell
P = artificially-placed sediment rate in the cell
R = artificially-removed sediment rate from the cell.

Residual in Equation 1 indicates the balancing of the cell (negative is eroding, positive is accreting, zero is balanced).

Each of the terms above has the units of volume per unit time (e.g., cu yd/yr), and the P and R terms represent regular maintenance activities such as dredging, bypassing, or nourishment. The region addressed in this study has experienced one or more of these activities, although not on a regular basis. This present study which produced the present-day sediment budget did not take into account such occasional placement or removal of sediment.

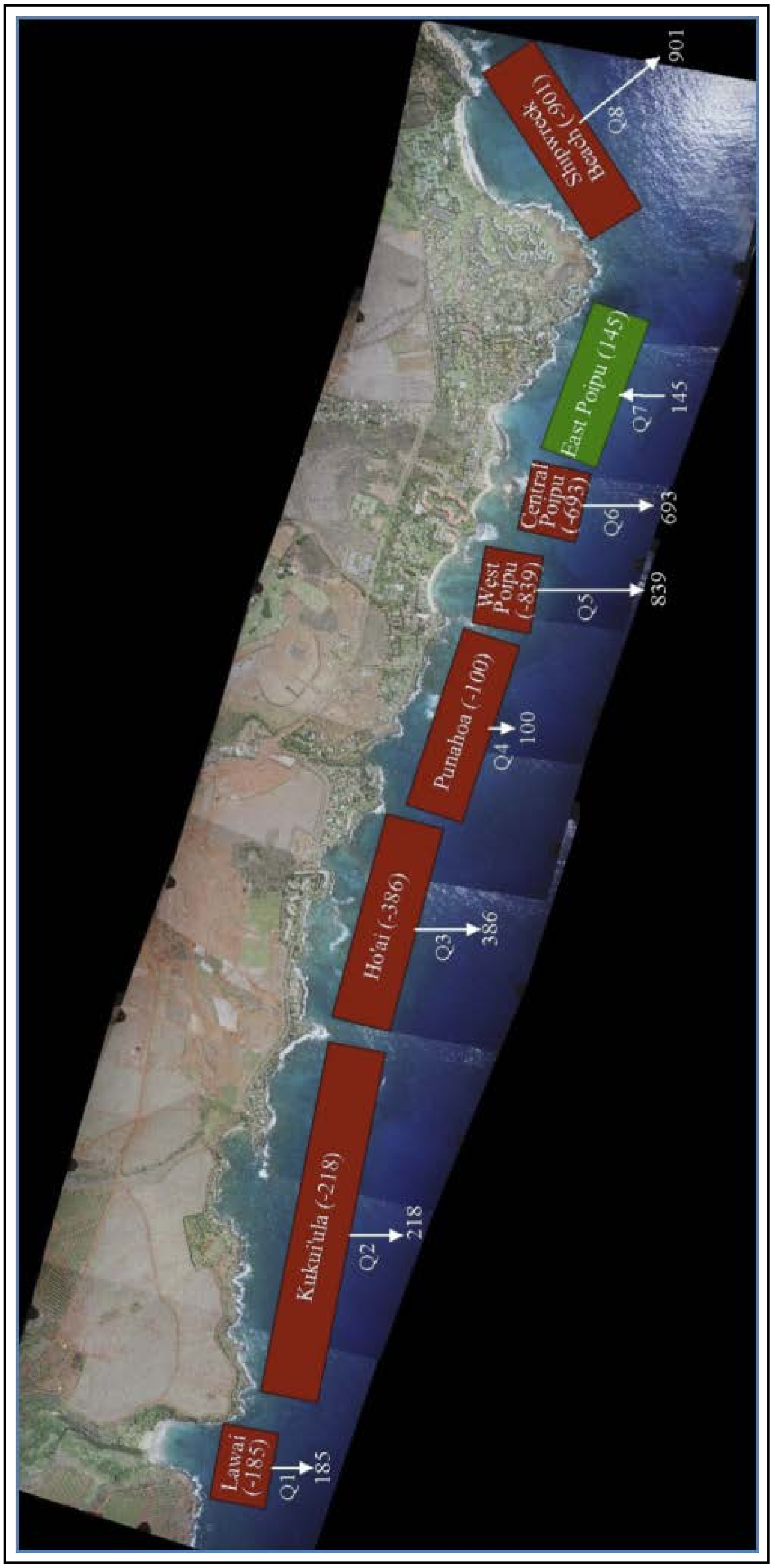

Figure 11. Sediment budget for Poipu Region, developed by using the Sediment Budget Analysis System (SBAS) (cu yd/yr).

PRACTICAL APPLICATION OF SBAS FOR DEVELOPMENT OF REGIONAL SEDIMENT BUDGETS. The ability to create a visualization of the calculated RSM sediment budget for the Poipu Region using SBAS toolbar within ArcGIS©10 helped to refine the preliminary sediment budget and also provided an invaluable communication tool for discussions with sponsors and stakeholders of the RSM program. The use of SBAS to generate sources, sinks, and flux rates was key in the process of balancing littoral cells for this application. Using SBAS within ArcView allows the user to overlay littoral cells and sediment pathways onto an aerial photo of the region, which helps to convey a practical understanding of how sediment movement occurs in the nearshore, and of how exchanges occur between cells in the overall region. Although not used in this application, the ability to integrate other data (such as shoreline change data or bathymetry) directly into ArcGIS could also prove highly valuable in development of the sediment budget by refining volume and flux numbers based on this additional spatial data.

The accuracy of a regional sediment budget and its subsequent ability to adequately capture shoreline dynamics depends on the quality of the input data. The input data used in both the Kauai RSM strategy (Moffatt and Nichol 2011) and this study were historical shorelines produced by the University of Hawaii Coastal Geology Group (UH CGG) (Fletcher et al. 2012) for the US Geological Survey (USGS) as part of the USGS Coastal Hazard Mapping program. The UH CGG recent shorelines are typically separated by a number of years. These shorelines were developed based on available aerial photographs which were not necessarily taken at the same time of the year. However, most of Hawaii's shoreline locations are seasonally dependent; frequent sampling is necessary to discern short-term seasonal responses from long-term trends. To capture (and remove) the seasonal effects, more frequent sampling would be necessary.

The Kauai RSM strategy (Moffatt and Nichol 2011) and this present study assume that 1.0 sq ft of beach change equates to 0.40 cu yd of material volume. This factor was developed for the Oahu Diamond Head to Pearl Harbor RSM strategy and is tentatively applied to the present project. The factor is a function of beach crest and toe elevations and can change from one beach to another beach. Profile analysis can help to determine the proper factor for each cell.

The use of shoreline change data to infer sediment transport characteristics requires a good working knowledge of the local dynamics. Experience with the individual cells was used whenever possible. Cross-shore sediment transport rates are difficult to calculate, and cross-shore transport patterns have been determined based on inferred local shoreline dynamics. As a result, a few quantities were estimated to balance the budget where applicable.

All of these points add uncertainty to the sediment budget calculations, and this uncertainty will exist until more data are available.

CONCLUSIONS. This CHETN has provided a brief overview of the development of regional sediment budgets in support of RSM activities on the Island of Kauai, Hawaii. This work developed a present-day sediment budget for littoral cells in the Poipu Region based on historical shoreline data provided by the University of Hawaii Coastal Geology Group (Fletcher et al. 2012). Many of the cells in the Poipu Region were closed to longshore transport, primarily by rocky headlands. The historical shoreline positions contain a level of uncertainty and cannot account for seasonal variation in the beaches. Additionally, sea level rise was not taken into account as a cause of shoreline recession.

Application of the commonly known "CERC formula" (USACE 2003) to estimate longshore sediment transport rates was attempted for the littoral cells of the Kekaha Region (Podoski 2013). Calibration of the *K* coefficient was possible only at the Waimea Beach cell of the Kekaha Region. The Waimea Beach cell consists of primarily terrigenous sediment. Use of the coefficient *K* at the other cells with calcareous beaches may not be valid, and when the CERC formula was used, it showed significant longshore transport into an area that is shown by the shoreline change analysis to be eroding. This was also confirmed by the wave model results, which contain a directionality factor. For these reasons, and also because most of the cells of the Poipu Region are closed, the CERC formula was not used. Sediment transport rates and sediment budgets may be refined as the result of more detailed measurements.

The wave modeling results could be improved by using offshore data results based on a spectral model that can resolve multiple wave trains occurring simultaneously. The Wave Information Study (WIS) data is parametric, and this shows only peak energy from one wave train.

ADDITIONAL INFORMATION. This Coastal and Hydraulics Engineering Technical Note (CHETN) was prepared by Sea Engineering, Inc., Waimanalo, HI, for the US Army Engineer District, Honolulu (POH), Honolulu, HI, as part of the Hawaii Regional Sediment Management (RSM) initiatives funded by the USACE RSM Program. Editorial revisions were provided by Jessica H. Podoski, POH. Additional information pertaining to the RSM Program can be found at the RSM website http://rsm.usace.army.mil

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ACRONYMS AND ABBREVIATIONS.

Term	Definition
CERC	Coastal Engineering Research Center
CHETN	Coastal and Hydraulics Engineering Technical Note
CHL	Coastal and Hydraulics Laboratory
ERDC	Engineer Research and Development Center
POC	Point of Contact
POH	US Army Engineer District, Honolulu, HI
RSM	Regional Sediment Management
SBAS	Sediment Budget Analysis System
UH CGG	University of Hawaii Coastal Geology Group
US	United States
USACE	US Army Corps of Engineers
USGS	US Geological Survey
WIS	Wave Information Study